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How Depth and Substratum Type Affect Diversity and Distribution Patterns of Echinoderms on the Continental Shelf in the South-eastern Adriatic Sea?

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Abstract: This study investigated how a combination of abiotic factors, and namely depth and substratum type, affected the spatial and temporal distribution of echinoderms on the continental shelf in the South-eastern Adriatic Sea. Samples were collected from 19 stations at depths from 0 to 120 m by scuba diving and bottom trawling. A total of 46 species belonging to the phylum Echinodermata were found. Substratum was the most important factor influencing the structure of echinoderm assemblages, while depth was not as important for the distribution pattern of echinoderms in the upper infralittoral zone of the Adriatic Sea. During the study period there were no seasonal differences among samples from the same sites. Species diversity of echinoderm assemblages was not significantly different between samples collected by scuba diving or bottom trawling, while species composition varied by sampling method.

Key words: echinoderms, substratum, depth, spatial distribution, Adriatic Sea

Introduction

Echinoderms are an important group of marine animals and many species fromof this group are considered to be key species for regulating community structure and balance, and allowing the survival of other organisms (Caso 1984). The phylum contains a variety of trophic groups, including detritivores, filter-feeders, grazers, scavengers and active predators, and as such plays an important role in the structure of benthic communities (Himmelman, Dutil 1991; McClintock 1994). The majority of echinoderm species usually are associated with a particular type of the sea bottom (rocky, sandy, or muddy). However, some species are more or less characteristic of a particular bottom community, which shapes considerably their distribution patterns (Zavodnik 1972). Sea urchins, in particular, play an important role in the structure of coastal communities by transforming large shallow rocky reefs covered by erect algae into overgrazed substrata dominated by encrusting coralline algae, the so-called ‘barrens’ (Shears, Babcock 2003). Benthic grazers can transform a great part of the consumed algae (up to 70%) to organic matter (Mills *et al*. 2000). Holothurians are one group of benthic invertebrates that is potentially affected by changes in chemical structure of substrata as they are deposit feeders (Ginger *et al*. 2001). Additionally, they may be useful indicators of pollution (Portocali *et al*. 1997), physical disturbance (Kaiser 1996), and some species (e.g. *Paracentrotus lividus, Holothuria tubulosa* and *Parastichopus regalis*) are commercially exploited (Conand, Sloan 1989).

Echinoderm assemblages were documented previously in the benthic fauna of the Adriatic Sea (Vatova 1949; Gamulin-Brida 1974; Šimunović 1997). Diversity and spatial distribution of echinoderms in the North and Middle Adriatic Sea are

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well studied (Heller 1868; Kolosváry 1936/37; Zavodnik 1960, 1961, 1988, 2003; Despalatović *et al*. 2009), while distribution patterns of echinoderms in the South-eastern Adriatic Sea are insufficiently explored and available data are still scarce (Babić 1913; Kolosváry 1938; Bruno 1972; Milojević 1979, 1984, 1986; Kašćelan *et al*. 2009). Some notes on echinoderms from this area are found in papers dealing with benthic communities from the Bay of Boka Kotorska and (or) the coast of the South Adriatic (Gamulin-Brida 1963, 1983; Karaman, Gamulin-Brida 1970; Stjepčević, Parenzan 1980; Petović, Marković 2013; Petović, Krpo-Ćetković 2014).

This study used data from diving to describe the diversity and spatial distribution of echinoderms related to depth, substratum type and sampling zone. These data are also used to investigate whether there were any seasonal changes in the echinoderm assemblages in the studied area; and data obtained by bottom trawling was used to investigate differences in species diversity and composition, between sampling methods.

Material and methods

Study area

The study area comprised the upper and middle parts of the continental shelf of the South-eastern Adriatic Sea, Montenegro (Fig. 1). This area consists of a semi-enclosed basin (the Bay of Boka Kotorska) and Adriatic coast. The bay stretches deep into the mainland (28.13 km) and it is one of the most indented parts of the Adriatic coast. The sea bottom is very complex with predominantly mud and sandy-mud substratum, while steep stones and rocks predominate the bottom along the shoreline. The Adriatic coast section varies in depth and bottom characteristics. The area near the entrance into the Bay of Boka Kotorska is characterised by a steep shoreline and cliffs changing into sandy areas at depths of 20–30 m. Further south, the coast becomes less steep and the depth increases gradually with the distance from the shore. The bottom consists of solid substrata that turn into fine sand and muddy sand. The study area extended to the mouth of the Bojana River, which deposits a huge quantity of fresh water and sediment

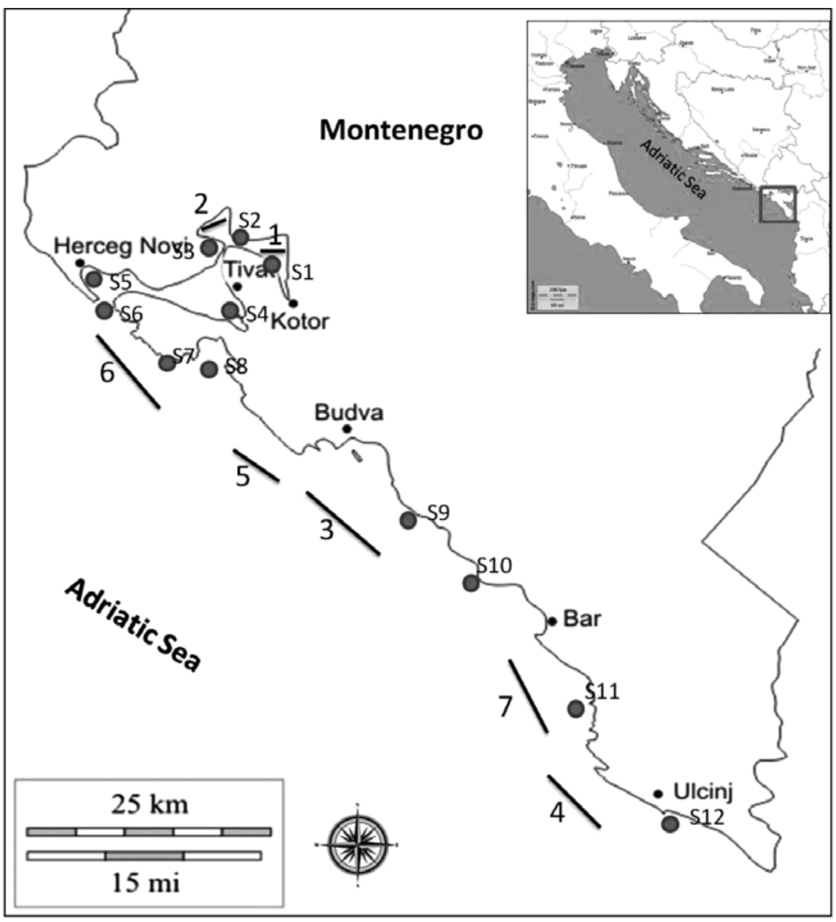


Fig. 1. Location of sampling stations on the continental shelf in the South-eastern Adriatic Sea, Montenegro (S1-S12 transects explored by scuba diving and 1-7 trawl net hauls)

into the sea. This part is shallow for a long way offshore and the seabed is mainly soft, consisting of fine sand and mud.

Sampling

Field-work was conducted from 2007 to 2009. The material was collected by scuba diving using a visual census method (from 0 to 38 m depth) and by trawl nets (from 25 to 120 m depth). Scuba sampling was done along permanent 100 m transect lines, positioned perpendicular to the coast, three times (spring, summer and autumn) during 2007. Material was collected along the transect line, one meter to the left and right of the line. Six transects were sampled by scuba diving in the Bay of Boka Kotorska and additional six transects on the Adriatic coast were sampled using scuba diving (Table 1). At seven locations (two in the Bay of Boka Kotorska and five on the Adriatic coast) material was collected by trawl nets (Table 2).

The collected material was immediately anaesthetised with a saturated solution of menthol in sea water and later preserved in 70% alcohol. Taxonomic identification was done following Tortonese (1965) and Koehler (1924), and later modified according to the European Register

Data analysis

The collected data was used for qualitative and quantitative estimation of the abundance and composition of echinoderms in the area. PRIMER v. 6 was used for statistical analysis. Univariate analysis used data from scuba diving, as well as the dataset from bottom trawling. Variables analysed were the number of species recorded at each station, Shannon–Wiener diversity index (H'), Margalef's index of species richness (d) and Pielou's evenness index (J') of marine species (Hansson 2001). Statistical analysis used a quantitative matrix of the data obtained by

Table 1. Locations studied by SCUBA diving (B-Boka Kotorska Bay; O-open sea)

Symbol	Zone	Latitude	Longitude	Sediment type	Depth (m)
S1	B	N 42° 26.247'	E18° 45.711'	Sand, mud	18
S2		N 42° 29.034'	E 18° 43.508'	Sand, mud	30
S3		N 42° 28.664'	E 18° 41.443'	Stone, mud	38
S4		N 42° 24.536'	E 18° 42.020'	Mud, sand	9
S5		N 42° 26.890'	E 18° 32.259'	Rock, sand	10
S6		N 42° 23.765'	E 18° 34.534'	Sand, mud	25
S7	O	N 42° 21.769'	E 18° 38.981'	Rock	20
S8		N 42° 21.496'	E 18° 41.312'	Rock	5
S9		N 42° 12.069'	E 18° 56.994'	Rock, sand	15
S10		N 42° 07.328'	E 19° 04.022'	Rock, sand	15
S11		N 42° 02.019'	E 19° 08.590'	Rock, sand	15
S12		N 41° 54.366'	E 19° 14.157'	Rock, sand	8

Table 2. Locations studied by bottom trawl net (B-Boka Kotorska Bay; O-open sea)

Symbol	Zone	Starting point	Ending point	Sediment type	Depth (m)
1	B	N42° 29.16' E 18° 40.68'	N 42° 30.68' E 18° 41.19'	Sand, mud	23-32
2		N 42° 28.05' E 18° 44.67'	N 42° 28.83' E 18° 42.53'	Sand, mud	29-39
3	O	N 42° 13.13' E 18° 48.29'	N 42° 10.35' E 18° 38.27'	Mud	80-120
4		N 41° 58.56' E 19° 08.04'	N 41° 57.67' E 19° 08.46'	Sand, mud	25-30
5		N 41° 14.08' E 18° 45.04'	N 42° 15.56' E 18° 40.04'	Mud	80-120
6		N42° 22.10' E 18° 34.20'	N42° 17.80' E 18° 43.20'	Mud	72-98
7		N42° 03.387' E19° 04.037'	N 41° 56.407' E 19° 06.990'	Mud	50-53

scuba diving along transects (fourth root transformation). Available data provided the spatial distribution of echinoderms according to depth range, substratum type, seasons and sampling zones. The Bray–Curtis dissimilarity index (Bray and Curtis, 1957) was used to analyse similarities between locations. Analysis of similarities (ANOSIM) was applied to test the differences between the species-station groups. A pair-wise test was carried out to evaluate the differences among depth strata. An individual species' contribution (up to about 90%) to average dissimilarity within each group was identified by the SIMPER procedure (Clarke, Warwick 2001).

Results

The collected material included 46 species of echinoderms belonging to five classes and 25 families. There were one species of crinoid (Crinoidea), 14 asteroids (Asteroidea), five ophiuroids (Ophiuroidea), 14 echinoids (Echinoidea) and 12 holothurians (Holothuroidea) (Table 3).

There were significant differences between the samples collected from locations in the Bay of Boka Kotorska and locations from the Adriatic coast (nMDS; R = 0.373; p = 0.001; Fig. 2). We found 21.01% average similarity between samples from the bay. Muddy bottom was present only inside the Bay of Boka Kotorska from the shallows to 25 m depth and was characterised by high abundance of *Ophiura albida* (36.83%). Also dominant on muddy substratum were *Holothuria tubulosa* (33.20%) and *H. polii* (12.62%). Along the coast around the bay up to 10 m depth the rocky substratum was populated by *Ophiotrix fragilis* (48.84%), *H. tubulosa* (16.80%) and *Paracentrotus lividus* (10.43%). The majority of the seabed inside the Bay of Boka Kotorska was covered by sand where the dominant species were *H.polii* (23.01%), *H. mammata* (6.37%) and *Sphaerechinus granularis* (4.55%). The samples from the Adriatic coast showed average similarity of 30.29%. The coast was characterised mainly by rocky shores with very steep cliffs and sand. The main components of the echinoderm communities on the rocky bottom were *P. lividus* (53.48%) and *Arbacia lixula* (31.95%). The dominant echinoderms on the sandy substratum were *H. polii* (23.01%), *Brissopsis lyrifera* (20.90%) and *S. granularis* (4.55%).

The species composition of samples collected from different depth strata (0–10, 11–25, 26–40 m) showed weak differences (R = 0.185; p = 0.001). The shallow depths inside the Bay of Boka Kotorska were dominated by *O. fragilis* (48.84%), *P. lividus* (24.00%), *H. tubulosa* (21.45%) and *H. polii* (18.18%). A similar depth stratum on the Adriatic coast was occupied mainly by *P. lividus* (50.83%) and *A. lixula* (34.28%). The echinoderm assemblage from sites deeper than 10 m in the bay was constituted mostly of *P. lividus* (27.13%), *O. fragilis* (15.67%) and *H. polii* (11.59%) while from the Adriatic coast locations at these depths the dominant species were *P. lividus* (50.83%), *A. lixula* (34.28%) and *B. lyrifera* (4.11%).

There were no significant differences in similarity of samples collected from the same locations during different seasons (R = -0.036; p = 0.992) (Fig. 3).

Univariate analyses were applied separately to data obtained by scuba diving and by bottom trawling (Fig. 4). The highest species diversity was found at site S6, while the lowest diversity was recorded at site S1. The number of species from scuba sites varied between five (S1) and 16 (S6), while the number of species collected by trawl net ranged from five (position 5) to 14 (position 7). Samples caught by trawl net had species diversity ranging from 2.61 (position 7) to 0.98 (position 5). Consequently, the lowest H' was found at station S2 which was dominated by muddy substratum. The evenness index was lowest for sediments with a high dominance of the ophiuroid *Ophiura albida* (S2) and the highest evenness was recorded at site S11.

Discussion

Our study provides the first description of the spatial distribution of echinoderms in the infralittoral zone along the coast of the South-eastern Adriatic Sea. These data provide the most widespread information on macrobenthic echinoderms in the area. According to published studies, the echinoderm assemblage on the continental shelf of the South-eastern Adriatic Sea comprises 57 species (Kašćelan *et al*. 2009). In a study of the mobile seafloor in the open part of the Northern and Middle Adriatic Sea, 34 species of echinoderms were recorded (Despalatović *et al*. 2009). The material collected in this study contained fewer species of ophiuroids than the nine species historically recorded (Kolosváry 1938; Gamulin-Brida 1963, 1983; Karaman, Gamulin-Brida 1970; Zavodnik 1972; Milojević 1979, 1982; Stjepčević, Parenzan 1980). Furthermore, macrobenthic species, such as echinoids and holothurians, were more abundant in the present study than previously recorded. The reason for this difference could be attributable to the different sampling methods: the historical data were obtained mainly by dredge and grab sampling gear that preferentially collects infau-

Table 3. List of echinoderm species collected on the continental shelf in the South-eastern Adriatic Sea with indications of zones (B-Bay of Boka Kotorska; O-open sea) and sampling methods

Class	Family	Species	B	O	SCUBA Diving	Trawl net
Crinoidea	Antedonidae	*Antedon mediterranea* (Lamarck, 1816)	x	x	x	x
Asteroidea	Asteriidae	*Coscinasterias tenuispina* (Lamarck, 1816)	x	x	x	
		Marthasterias glacialis (Linnaeus, 1758)	x	x	x	x
	Asterinidae	*Anseropoda placenta* (Pennant, 1777)		x		x
	Astropectinidae	*Astropecten bispinosus* (Otto, 1823)		x		x
		Astropecten irregularis pentacanthus (Delle Chiaje, 1827)	x	x		x
		Astropecten jonstoni (Delle Chiaje, 1827)		x	x	
		Astropecten platyacanthus (Philippi, 1837)	x	x	x	
		Tethyaster subinermis (Philippi, 1837)		x		x
	Echinasteridae	*Echinaster (Echinaster) sepositus* (Retzius, 1783)	x	x	x	x
	Goniasteridae	*Peltaster placenta* (Müller & Troschel, 1842)		x		x
	Luidiidae	*Luidia ciliaris* (Philippi, 1837)		x		x
		Luidia sarsi Düben & Koren, 1845		x		x
	Ophidiasteridae	*Hacelia attenuata* Gray, 1840		x	x	
		Ophidiaster ophidianus (Lamarck, 1816)	x	x	x	
Ophiuroidea	Ophiodermatidae	*Ophioderma longicauda* (Bruzelius, 1805)	x	x	x	x
	Ophiomyxidae	*Ophiomyxa pentagona* (Lamarck, 1816)		x		x
	Ophiotrichidae	*Ophiothrix fragilis* (Abildgaard, 1789)	x	x	x	x
	Ophiuridae	*Ophiura albida* Forbes, 1839	x		x	x
		Ophiura ophiura (Linnaeus, 1758)		x		x
Echinoidea	Arbaciidae	*Arbacia lixula* (Linnaeus, 1758)	x	x	x	
	Brissidae	*Brissopsis lyrifera* (Forbes, 1841)	x	x	x	x
		Brissus unicolor (Leske, 1778)	x	x	x	
	Cidaridae	*Cidaris cidaris* (Linnaeus, 1758)	x	x	x	x
	Echinidae	*Echinus acutus* Lamarck, 1816		x		x
		Echinus melo Lamarck, 1816		x		x
		Paracentrotus lividus (Lamarck, 1816)	x	x	x	
		Psammechinus microtuberculatus (Blainville, 1825)		x		x
	Diadematidae	*Centrostephanus longispinus* (Philippi, 1845)		x	x	x
	Loveniidae	*Echinocardium cordatum* (Pennant, 1777)	x	x	x	
		Echinocardium fenauxi Péquignat, 1963	x		x	
	Schizasteridae	*Schizaster canaliferus* (Lamarck, 1816)	x		x	
	Spatangidae	*Spatangus purpureus* (O.F. Müller, 1776)	x	x	x	
	Toxopneustidae	*Sphaerechinus granularis* (Lamarck, 1816)	x	x	x	
Holothuroidea	Cucumariidae	*Leptopentacta elongata* (Düben & Koren, 1846)	x			x
		Leptopentacta tergestina (M, Sars, 1857)	x			x
		Ocnus planci (Brandt, 1835)	x	x	x	x
		Ocnus syracusanus (Grube, 1840)	x	x		x
	Holothuriidae	*Holothuria (Panningothuria) forskali* Delle Chiaje, 1823	x	x	x	
		Holothuria (Thymiosycia) impatiens (Forskål, 1775)	x	x	x	
		Holothuria (Holothuria) mammata Grube, 1840*	x	x	x	
		Holothuria (Roweothuria) poli Delle Chiaje, 1823	x	x	x	
		Holothuria (Platyperona) sanctori Delle Chiaje, 1823		x	x	
		Holothuria (Holothuria) tubulosa Gmelin, 1790	x	x	x	x
	Stichopodidae	*Parastichopus regalis* (Cuvier, 1817)	x	x		x
	Synallactidae	*Mesothuria intestinalis* (Ascanius, 1805)	x		x	

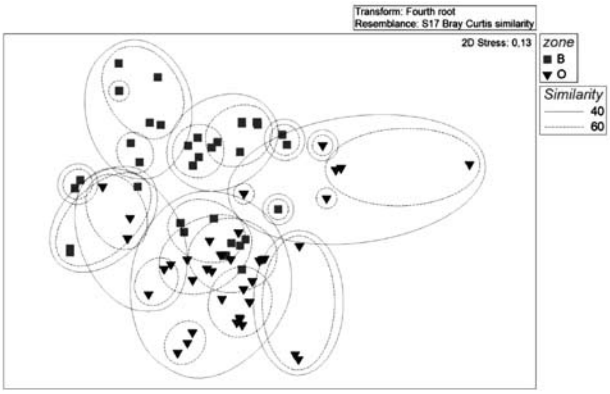


Fig. 2. Multidimensional scaling ordination of the sampling stations with indication of sampling zones

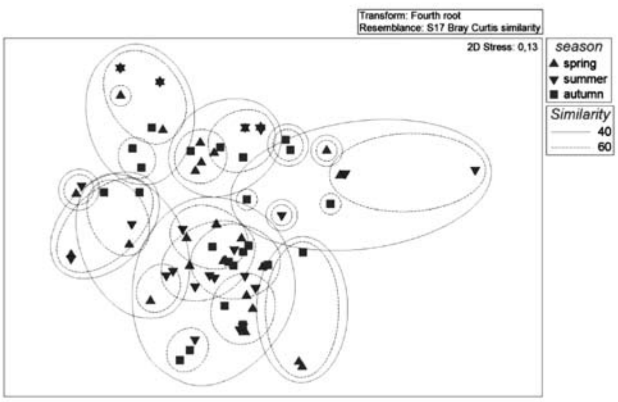


Fig. 3. Multidimensional scaling ordination of the sampling stations with indication of sampling period

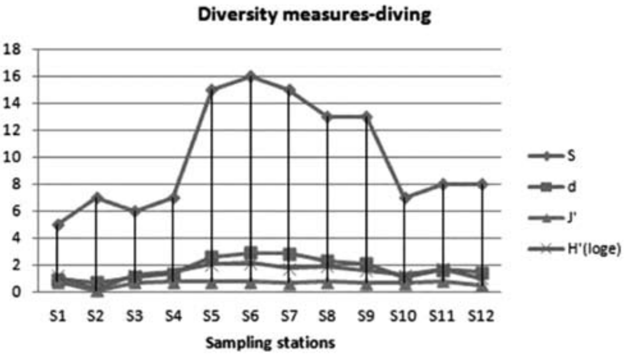
nal echinoderm species (Zavodnik 1972; Stjepčević, Parenzan 1980), while the present study was conducted by scuba diving and trawl nets. Moreover, previous samplings were done in deeper parts of the Montenegrin coast, and the rocky seashore was not well explored.

We found significant differences in the number of species and their abundance between samples collected from the Bay of Boka Kotorska and the Adriatic coast. This result was expected because echinoderms are a complex taxonomic group of species with very different ecological preferences, and there were evident differences in morphological and ecological conditions between these two zones. A high abundance of *O. albida* was recorded on mud substratum, supporting the observations of earlier authors (Karaman, Gamulin-Brida 1970; Milojević 1979) and contributing greatly to the differentiation between bay and Adriatic coast samples. Muddy substrata were also populated by holothurians *Leptopentacta elongata* and *L. tergestina*, species typical of the biocoenosis of muddy bottoms (Milojević, 1979). The greater part of the bay coastline was rocky, and the parts close to the open sea were occupied mainly by *P. lividus* and *A. lixula* up to 25 m in depth. Analysis of collected materials showed that *H. polii* and *H. tubulosa* were present on rocky, as well as on muddy seafloor, both in shallow waters and updown to 25 m depth. The ophiuroid *Ophiotrix fragilis* made up a large proportion of the composition of the echinoderm assemblage characteristic of hard substrata in the Bay of Boka Kotorska. This species is widespread and the most common ophiuroid in the Adriatic Sea (Zavodnik 1967; Milojević 1979). The echinoderm assemblage of the sandy substratesubstratum inside the bay was mainly comprised of the holothurians *H. polii* and *H. mammata*, and the sea urchin *S. granularis,* while on the Adriatic coast we also recorded *B. lyrifera*. The rocky shore along the Adriatic coast is characterised by very steep sub-vertical and vertical cliffs sloping abruptly down to 20–30 m depth. In the areas where barrens predominated, *P. lividus* and *A. lixula* dominated updown to 25 m. The influence of substratum on echinoderm distribution may be connected with predator-prey interactions, resource partitioning or locomotion (Ellis and Rogers 2000).

Depth has been indicated as an important factor influencing the structure of demersal assemblages (Kaiser *et al.* 1999; Ellis, Rogers 2000; Despalatović *et al.* 2009). Nevertheless, our results showed weak differences between samples collected from different depth strata. A possible explanation is that our statistical analysis only considered depth strata 0–10 m and 11–25 m, excluding the stratum 26–40 m which contained only one sample, insufficient for analysis. The species collected during our study have a wide bathymetric distribution in the Adriatic Sea (Vidović-Matvejev 1978).

Echinoderms are sessile and slow-moving organisms (Tortonese 1965), therefore the results obtained showed no differences among samples collected from different seasons at the same sites. Moreover, analysis of temporal variation of echinoderm assemblages from soft substrata of the Çanakkale Strait (Turkish Strait System) also detected no seasonal differences (Aslan-Cihangir, Pancucci-Papadopolou 2012).

Many studies have addressed appropriate sampling gear for the collection of echinoderms and it is clear that one method is not sufficient. Pérès and Gamulin-Brida (1973) stated that bottom trawl nets result in a qualitatively accurate reflection of epifaunal composition of the seafloor biocoenosis, while Zavodnik (1971) stated that bottom trawls are deficient because they do not sample animals that are deeply burrowed in the sediment, reducing estimates



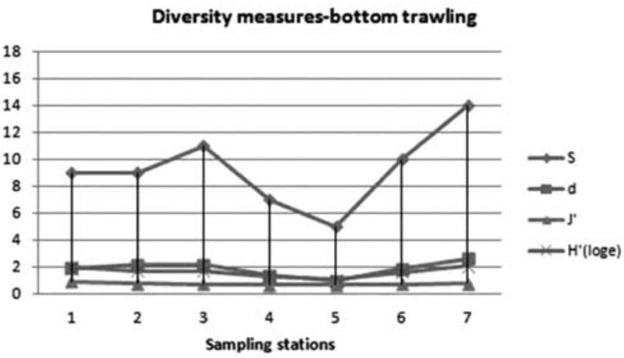


Fig. 4. Spatial variability of the principal biodiversity parameters: number of species (s), Shannon-Wiener diversity index (H'), Margalef's index of species richness (d) and Pielou's evenness index (J')

of composition and biomass of biocoenoses on mobile substrata. Using bottom trawl on mobile substrata results in collecting mostly holothurians, sea stars and sea urchins while grab sampling is more suitable for sampling of ophiuroids and burrowed species (Despalatović *et al*. 2009; Aslan-Cihangir, Pancucci-Papadopolou 2012). We compared scuba diving and bottom trawling as methods. According to our results, almost all sites were characterised by high species diversity. There were no significant differences in species richness of samples collected by trawl net or scuba diving. With regard to species composition, more echinoid species (11) were collected by diving than by bottom trawl (six).This pattern was the same for holothurians (eight species collected by diving, six by trawl net), while less ophiuroids and asteroids were caught by diving than by trawl net. Therefore, there were no significant differences between species diversity of samples collected by different methods but species composition differed between methods.

In conclusion, the type of substratum was the most important factor influencing the structure of echinoderm assemblages in the studied area. Analyses of species composition and abundance indicated that depth did not play a significant role to the distribution of echinoderms in the upper infralittoral zone of the temperate Adriatic Sea. During the study period, no seasonal differences were noted in samples from the same sites. Species diversity of echinoderm assemblages sampled by scuba diving or bottom trawling were not significantly different but species composition varied by sampling method.

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